Appendix D.1

Hanford Sitewide SSHAC Level 3 PSHA Project

March 18, 2014

Hazard Input Document (HID)
Final SSC Model

Contents

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Hazard Input Document (HID)
Final SSC Model

This document is the Hazard Input Document (HID) that describes the Final Seismic Source Characterization (SSC) model for the Hanford PSHA. The goal of this HID is to provide sufficient information for the hazard analyst to unequivocally input the SSC model into the hazard code for calculations. In some cases, to avoid making the main text of this document unnecessarily bulky, tables defining some elements of the SSC model are included as appendices.

Description of Seismic Sources

Four types of seismic sources are identified in the model: seismic source zones, fault sources, and the Cascadia subduction zone (CSZ) intraslab and plate interface sources.

Characteristics that are applicable to both the seismic source zones and fault sources are discussed first, followed by characteristics of source zones, fault sources, and CSZ sources.

Common Characteristics for Source Zones and Fault Sources

This section includes elements of the SSC model that are common to seismic source zones and fault sources.

Rupture Size and Geometry

Future earthquake ruptures are assessed to have rupture areas that are magnitude-dependent in the hazard calculations. The magnitude dependency for rupture area A is given by the following relationships as given by Hanks and Bakun (2008):

$\mathbf{M}$ = log A + 3:98 for A≤ 537 km^2; and
$\mathbf{M}$ = 1.33 log A + 3:07 for A>537 km^2.

Focal Depth Distribution for Future Earthquakes

Within the seismic source zones and along fault sources, the depth distribution of future moderate-to-large earthquake focal depths is defined by a combination of the focal depth distribution for small-magnitude earthquakes and magnitude-dependent models for the location of the hypocenter relative to the rupture for reverse faults. The starting focal depth distribution for the YFTB source zone and faults within that zone is given in the file *FocalDepth_Dist.xlsx* and the distributions for Zones B, C, and D are given the file *DepthAnalysis_EM185.xlsx.* For each magnitude, rupture area is calculated using the inverse of Hanks and Bakun. For the rupture length-to-width aspect ratio, the model for reverse faulting defined in Appendix B of Chiou and Youngs (2008) until the width reaches the maximum is defined by the crustal thickness and the dip. For each possible focal depth (defined in 1-km increments centered at the center (e.g., 0.5, 1.5, etc.), the distribution for the location of the hypocenter with respect to the rupture for reverse faults defined in Appendix B of Chiou and Youngs (2008) defines a distribution for how to place the rupture on the hypocenter. If the rupture extends above the surface or below the seismogenic thickness, that case is discarded. Summing the weights for the remaining cases (product of the focal depth frequency and the probability of hypocenter location) and normalizing the results produces a distribution for distance to the top of the rupture (Ztor) that is a function of magnitude, dip, and thickness. The distribution is given in the file *Ztor_dist.xlsx*.

Seismic Source Zones

Four seismic source zones are identified, as given in Table 1 below.

Table 1. Seismic Source Zones

Zone Name	Identifier
Yakima Fold and Thrust Belt Background	YFTB
Mid-C Study Zone B	Zone B
Mid-C Study Zone C	Zone C
Zone D	Zone D

The seismic source zones are shown in Figure 1 and the coordinates for the zones are given in the file *Source Zone Coords* tab in the file *HID_alltables_20140317.xlsx*.

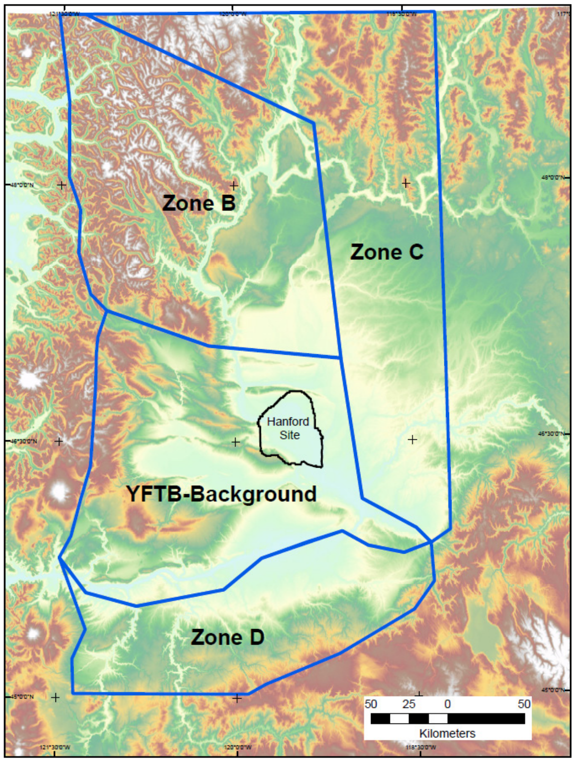

Figure 1. Seismic Source Zones

The logic tree for the seismic source zones is shown in Figure 2. The three epistemic assessments are seismogenic thickness, maximum magnitude, and spatial variation of recurrence parameters. An additional epistemic assessment for the YFTB source zone is whether or not the observed seismicity is associated with the fault sources. Aleatory (relative frequency) assessments define the characteristics of future ruptures within the source zones. The aleatory assessments are discussed below but, because they are aleatory and not epistemic, they are not shown in the logic tree.

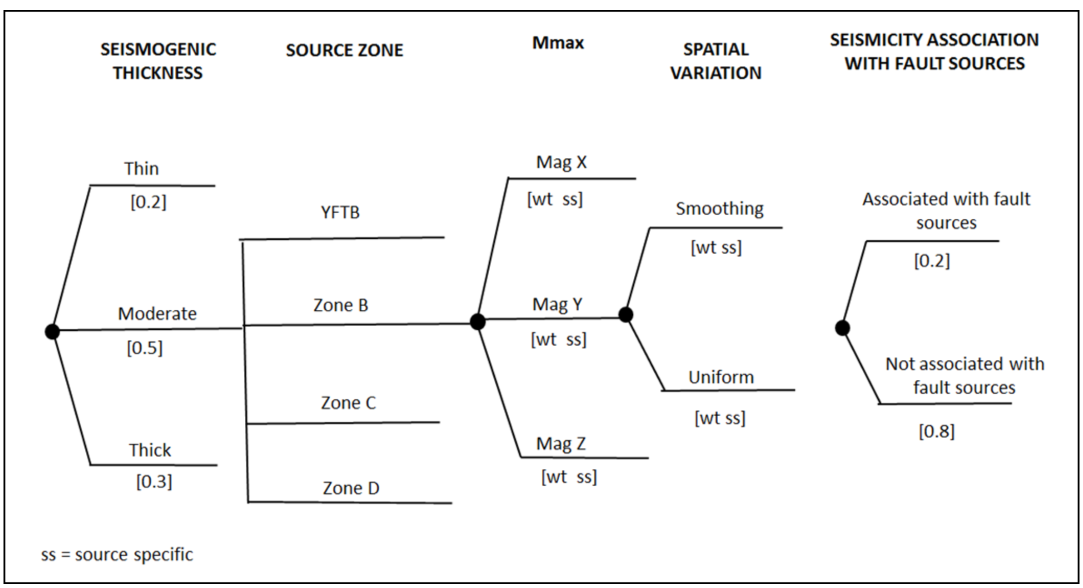

Figure 2. Logic Tree for the Seismic Source Zones

"Leaky" Source Boundaries

All simulated epicenters fall within the seismic source of interest, but boundaries can either allow or not allow ruptures within a source zone to proceed into adjacent sources. All source zone boundaries in the model are assessed to be leaky.

The characteristics that are specific to each seismic source zone are given below.

YFTB Background Zone (YFTB)

The YFTB source zone is the only source zone that includes fault sources within its boundaries, thus it is a "background" zone to the fault sources.

Seismogenic Crustal Thickness

The following epistemic alternatives define the assessment of seismogenic crustal thickness for all seismic sources:

Thin	[0.2]
Moderate	[0.5]
Thick	[0.3].

Seismogenic crustal thickness is assumed to be consistent across all sources; i.e., results assuming a thin seismogenic thickness for one source are only combined with results making the same assumption for all other sources.

For the YFTB and all of the fault sources that occur within the YFTB zone, the definitions are as follows:

Thin	13 km
Moderate	16 km
Thick	20 km.

The rupture size and geometry follow the assessments described above in Common Characteristics of Seismic Source Zones and Fault Sources. The focal depth distribution for future earthquakes is truncated at depth by the seismogenic crustal thickness.

Maximum Earthquake Magnitude

The maximum magnitude distribution for the YFTB source is as follows:

6.5	[0.3]
6.75	[0.4]
7.0	[0.3].

Earthquake Recurrence

Earthquake recurrence for the YFTB source zone is characterized by a Poisson process and all earthquakes are assumed to be independent events. For all seismic source zones, the doubly truncated exponential distribution (Gutenberg and Richter 1956) is assumed. Earthquake recurrence rates are calculated for seismic source zones using the approach described by Johnston et al. (1994) that uses a Bayesian approach for maximum likelihood estimation of (a,b) parameters that are conditional on M_{max}. The calculations also include the uncertainties in magnitude by using the N* approach in NUREG-2115 (NRC 2012) (Chapter 3.0). A single evaluation of completeness is used for all of the seismic sources.

The assessment of recurrence is a function of whether or not some of the seismicity within the YFTB source zone is associated with the fault sources or is assessed to not be associated with the fault sources (Figure 2). The weights associated with these alternatives are as follows:

Observed seismicity is associated with fault sources	[0.2]
Observed seismicity is not associated with fault sources	[0.8].

If the seismicity is assessed to be associated with fault sources, the seismicity within the polygon capture areas is removed from the YFTB source zone recurrence calculation. The map of the capture areas is given in the *Capture Area Geometry* tab of the file *FAULTS_exp_20131114.xlsx* and the coordinates for the capture areas are given in the file *Capture_area-coordinates_20131018.xlsx.*

Source-specific recurrence parameters for the YFTB source zone are tabulated in the (RECURRENCE_ZONES.*xlsx)* document.

Spatial Variation of Recurrence

The spatial variation of earthquake recurrence parameters for the YFTB source zone is assessed to be either uniform or varying such that spatial smoothing should be applied. Spatial smoothing of a-values is done using the earthquakes having magnitudes $\mathbf{M}\geq 3$ and an adaptive kernel that accounts for the spatial density of earthquake epicenters.

Uniform	[0.8]
Smoothing	[0.2].

Style of Faulting and Geometry of Ruptures

The style of faulting, strike, and dip of ruptures within seismic source zones are source-specific aleatory assessments. The style of faulting of future ruptures within the YFTB zone is defined by the following aleatory (relative frequency) distribution:

Reverse	(60%)
Normal	(20%)
Strike slip	(20%).

The strike of ruptures is dependent on the style of faulting:

Reverse	
40º	(20%)
90º	(60%)
140º	(20%)

Normal

10º	(20%)
90º	(60%)
140º	(20%)

Strike slip

60º	(50%)
150º	(50%).

The dip of ruptures is dependent on the style of faulting (dip direction is random):

Reverse

30º	(20%)
50º	(60%)
70º	(20%)

Normal

40º	(20%)
60º	(60%)
80º	(20%)

Strike slip

70º	(40%)
90º	(60%).

Zones B, C, and D

Seismogenic Crustal Thickness

For source Zone B, the following definition applies:

Thin =	10 km
Moderate =	12 km
Thick =	15 km.

For Zone C, the following definition applies:

Thin =	13 km
Moderate =	16 km
Thick =	20 km.

For Zone D, the following definition applies:

Thin =	15 km
Moderate =	20 km

Thick = 24 km.

Maximum Earthquake Magnitude

The distribution of Mmax for zones B, C, and D is as follows:

6.5 [0.2]
6.75 [0.5]
7.0 [0.2]
7.25 [0.09]
7.5 [0.01].

Earthquake Recurrence

Earthquake recurrence is calculated for Zones B, C, and D in the same manner as the YFTB Zone and the source-specific recurrence parameters are given in the file RECURRENCE_ZONES.*xlsx*.

Spatial Variation of Recurrence

The spatial distribution of recurrence parameters for the source zones is as follows:

Zone B
Smoothing [1.0]

Zone C
Uniform [1.0]

Zone D
Uniform [0.8]
Smoothing [0.2].

Style of Faulting and Geometry of Ruptures

The style of faulting of future ruptures within Zones B, C, and D is defined by the following aleatory distribution:

Reverse (60%)
Strike slip (40%).

The strike and dip of ruptures are defined by uniform aleatory distributions.

The characteristics of seismic source zones are summarized in Table 2.

Table 2. Summary of Seismic Source Zone Characteristics[a]

	YFTB	Zone B	Zone C	Zone D
Seismogenic Thickness	13 km [0.2] 16 km [0.5] 20 km [0.3]	10 km [0.2] 12 km [0.5] 15 km [0.3]	13 km [0.2] 16 km [0.5] 20 km [0.3]	15 km [0.2] 20 km [0.5] 24 km [0.3]
Style of Faulting	Reverse (60%) Normal (20%) Strike slip (20%)	Reverse (60%) Strike slip (40%)	Reverse (60%) Strike slip (40%)	Reverse (60%) Strike slip (40%)
Strike of Ruptures	<u>Reverse</u> 40º (20%) 90º (60%) 140º (20%) <u>Normal</u> 10º (20%) 90º (60%) 140º (20%) <u>Strike slip</u> 60º (50%) 150º (50%)	0-360° uniform (100%)	0-360° uniform (100%)	0-360° uniform (100%)
Dip of Ruptures	<u>Reverse</u> 30º (20%) 50º (60%) 70º (20%) <u>Normal</u> 40º (20%) 60º (60%) 80º (20%) <u>Strike slip</u> 70º (40% 90º (60%) Dip direction is random	Not modeled[b]	Not modeled	Not modeled
Mmax	6.5 [0.3] 6.75 [0.4] 7.0 [0.3]	6.5 [0.2] 6.75 [0.5] 7.0 [0.2] 7.25 [0.09] 7.5 [0.01]	6.5 [0.2] 6.75 [0.5] 7.0 [0.2] 7.25 [0.09] 7.5 [0.01]	6.5 [0.2] 6.75 [0.5] 7.0 [0.2] 7.25 [0.09] 7.5 [0.01]
Max Observed[c]	M 4.79 1918-11-17	M 7.06[d] 1872-12-15 Lake Chelan	M 5.98 1936-07-16 Milton-Freewater	M 4.8 1893-03-06
Seismicity Association	Assoc with faults [0.2] Not assoc. [0.8]	Not applicable	Not applicable	Not applicable
Spatial Variation of Recurrence Parameters	Uniform [0.8] Smoothing [0.2]	Smoothing [1.0]	Uniform [1.0]	Uniform [0.8] Smoothing [0.2]

(a) Epistemic weights are given as probabilities in [brackets] and aleatory relative frequencies are given as percentages in (parentheses).
(b) Because of the large distance to the sites, the dip of ruptures is not modeled but is assumed to be vertical.
(c) Magnitudes given are the expected magnitudes, E[M], in the Hanford PSHA earthquake catalog.
(d) Bakun et al. (2002) magnitude estimate is M 6.5 – 7.0 at the 95th confidence level.

Fault Sources

The fault sources consist of the faults associated with YFTB, as well as the Seattle fault. For purposes of assessing the slip rates and recurrence, some of the faults have also been identified according to individual segments, as shown in Table 3.

Table 3. Fault Sources Including Fault Segments

Ahtanum Ridge	AR
Arlington	AF
Cleman Mountain	CM
Columbia Hills	CH
Columbia Hills Central-East	CH-C-E
Columbia Hills East	CH-E
Columbia Hills West	CH-W
Columbia Hills-Central	CH-C
Columbia Hills-Central-West	CH-C-W
Frenchman Hills	FH
Horn Rapids Fault	HR
Horse Heaven Hills	HHH
Horse Heaven Hills Central	HHH-C
Horse Heaven Hills Central-East	HHH-C-E
Horse Heaven Hills Central-West	HHH-C-W
Horse Heaven Hills West	HHH-W
Laurel	LF
Luna Butte	LB
Manastash Ridge	MR
Manastash Ridge-Central	MR-C
Manastash Ridge-East	MR-E
Manastash Ridge-West	MR-W
Maupin	MF
Rattles of the Rattlesnake Wallula Alignment	RAW
Rattlesnake Hills	RH
Rattlesnake Mountain	RM
Saddle Mountain	SM
Saddle Mountain-East	SM-E
Saddle Mountain-West	SM-W
Seattle Fault	SFZ
Selah Butte	SB
Toppenish Ridge	TR
Toppenish Ridge East	TR-E
Toppenish Ridge West	TR-W

Table 3. (contd)

Umtanum Ridge	UR
Umtanum Ridge-Southeast Anticline	UR-SA
Umtanum Ridge-Gable Mountain	UR-GM
Umtanum Ridge-Central	UR-C
Umtanum Ridge-East	UR-E
Umtanum Ridge-West	UR-W
Wallula Fault	WF
Yakima Ridge	YR
Yakima Ridge East	YR-E
Yakima Ridge West	YR-W
Yakima Ridge-Southeast	YR-SE

The fault sources in the YFTB region are shown in Figure 4a, b and the coordinates for the fault sources, as well as the fault segments, are given in the *Entire Fault Coords* and the *Fault Segment Coords* tabs in the file *HID_alltables_20140317.xlsx*.

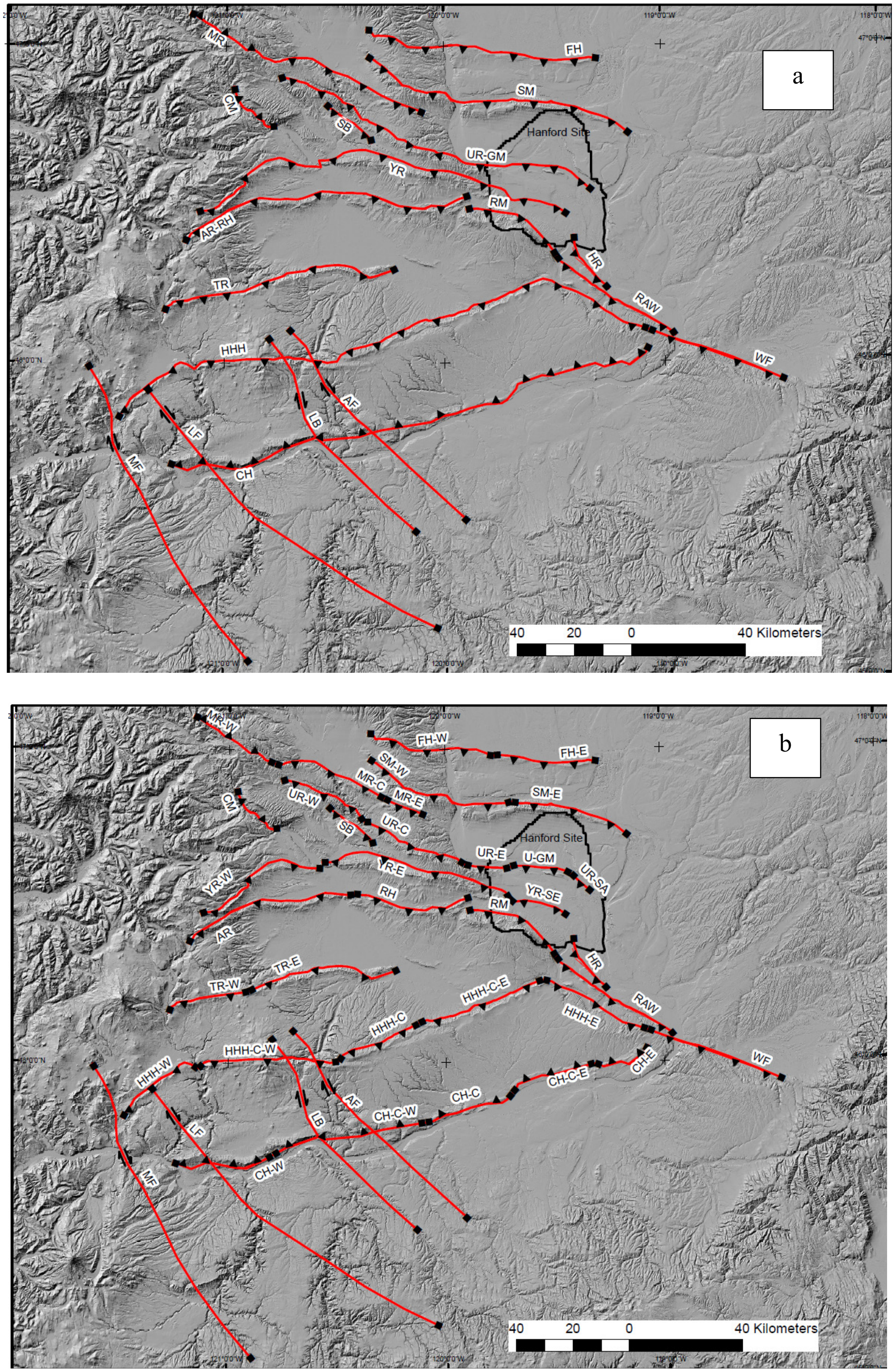

Figure 4a. Fault Sources, and 4b Fault Segments. Teeth are shown on the hanging wall of the faults and squares define the segment boundaries.

The characteristics of fault sources are summarized below in three logic trees that define the geometry and slip rates, characteristic magnitudes, and earthquake recurrence associated with each fault source.

Fault geometries, slip rates, and recurrence rates are assessed for individual fault segments (given in Table 3), such that variations in these characteristics can occur along the lengths of the fault sources. The characteristic magnitudes, Mchar, are assessed for the entire fault source and ruptures associated with characteristic magnitudes can occur anywhere along the fault source.

Geometry and Net Slip Rate of Fault Segments

Shown in Figure 5 is the logic tree that includes the elements of the SSC model that result in net slip rates for each fault segment shown in Figure 4. The first two nodes of the fault logic tree are the seismogenic thickness and the basis for assessing fault dip, which are assessments common to all of the fault sources in the model and are independent of each other.

All of the fault sources that lie within the YFTB source zone share the same assessment of seismogenic thickness (see discussion of YFTB source zone). The Seattle fault characteristics are those developed as part of the BC Hydro PSHA (BC Hydro 2012, Figure G-CO9).

Alternative branches for seismogenic thickness lead to alternative values of fault dip for a given width of polygon defining the limits of structural relief associated with each fault segment. An additional source of uncertainty in fault dip is whether the maximum, the average, or 60% of the average width of the structural relief polygon is used to assess the fault dip, as shown as the “basis for fault dip” node of the logic tree. The weights associated with these three alternative approaches are as follows:

Use of maximum polygon width	[0.2]
Use of average polygon width	[0.5]
Use of 60% of average polygon width	[0.3].

The assessment of basis for fault dip is a global assessment and is correlated across all faults sources.

The remaining assessments are fault-segment-specific, as indicated by the vertical bar in the tree. Assessments that are source-specific are labeled as “ss” in Figure 5. The *Fault Segments* tab of the file *HID_alltables_20140317.xlsx* provides the fault segment-specific assessments.

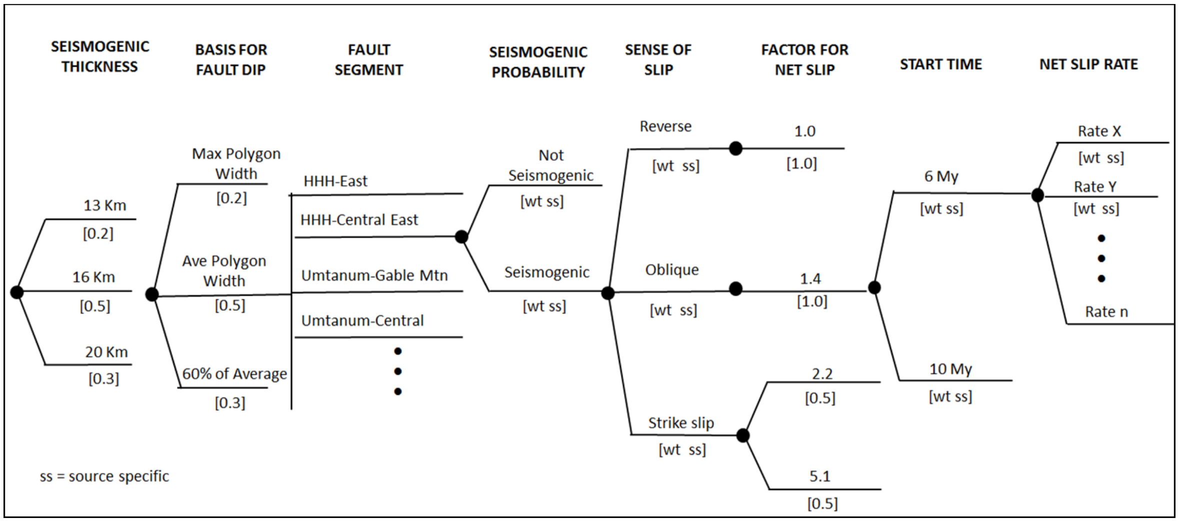

Figure 5. Logic Tree for the Fault Segment Geometry and Slip Rate

The seismogenic probability p[S] is an assessment of whether the fault source should be included in the SSC model. All faults except the Arlington, Luna Butte, Laurel, and Maupin faults are assessed to have a p[S] = 1.0. The Arlington, Luna Butte, Laurel, and Maupin faults have p[S] = 0.4.

Given the dip of each fault segment and the seismogenic thickness, the downdip width of each fault segment is defined.

The average structural relief for each fault segment, which defines the vertical component of slip, is given in the *Fault Segments* tab of the file *HID_alltables_20140317.xlsx*. Together, the dip of the fault segment and the structural relief define the average amount of dip slip.

The next node of the logic tree is the sense of slip on each fault segment, which defines the components of lateral and dip slip. The weights associated with the alternative senses of slip for the fault segments are given in Table 4.

Table 4. Sense of Slip for Fault Segments

	Sense of Slip		
Fault Segment	Reverse	Oblique	Strike Slip
A-RH: Ahtanum segment	0.5	0.5	
A-RH: Rattlesnake Hills segment	0.9	0.1	
Arlington			1.0
Cleman Mtn	0.3	0.7	
Columbia Hills-all segments	1.0		
Frenchman Hills-all segments	1.0		

Table 4. (contd)

Fault Segment	Sense of Slip		
	Reverse	Oblique	Strike Slip
Horn Rapids Fault	0.6	0.4	
Horse Heaven Hills-East	0.8	0.2	
HHH-all other segments	1.0		
Laurel			1.0
Luna Butte			1.0
Manastash-all segments	0.9	0.1	
Maupin			1.0
Rattlesnake Mtn	0.9	0.1	
RAW	0.4	0.6	
Saddle Mtn-all segments	1.0		
Selah Butte	0.3	0.7	
Toppenish Ridge-all segments	0.9	0.1	
Umtanum Ridge-all segments	0.9	0.1	
Wallula fault	0.3	0.6	0.1
Yakima Ridge-all segments	0.9	0.1	

In terms of the correlation among segments of a given fault, the cases where all segments of a given fault have the same sense of slip are indicated in Table 4. For the other cases, their weights are as follows:

Ahtanum-Rattlesnake Hills:

- Both segments are reverse [0.5]
- Only RH segment is reverse [0.4]
- Both segments are oblique [0.1]

Horse Heaven Hills:

- All segments are reverse [0.8]
- HHH-East is oblique; others are reverse [0.2].

The factors for multiplying the dip slip to arrive at the net slip are given in the next node of the logic tree. These assessments are the same for all fault segments.

Factors to multiply the dip slip to obtain net slip:

Reverse
1.0 [1.0]
Oblique
1.4 [1.0]
Strike Slip

2.2 [0.5]
5.1 [0.5].

Applying these factors, the net slip for each fault segment is then calculated. To assess net slip rate, alternative start times for the deformation is the next node of the logic tree. The weights associated with the alternative start times are given in Table 5.

Table 5. Start Times and Weights for Calculating Slip Rate for Fault Segments

	Start Time for Slip Rate	
Fault Segment[(a)]	6 Myr	10 Myr
Ahtanum-Rattlesnake Hills	0.4	0.6
Cleman Mtn	0.4	0.6
Columbia Hills	0.4	0.6
Frenchman Hills	0.4	0.6
Horn Rapids Fault	0.3	0.7
Horse Heaven Hills	0.3	0.7
Manastash	0.4	0.6
Rattlesnake Mtn	0.3	0.7
RAW	0.3	0.7
Saddle Mtn	0.4	0.6
Selah Butte	0.4	0.6
Toppenish Ridge	0.4	0.6
Umtanum Ridge	0.4	0.6
Wallula fault	0.3	0.7
Yakima Ridge	0.4	0.6

(a) The assessments shown are applicable for all segments of the fault named.

The correlation across all faults in start times is as follows:

All faults have start time of 10 My	[0.6]
Only HR, HHH, RM, RAW, and WF have start time of 10 MY	[0.1]
All faults have start time of 6 My	[0.3]

The Rattlesnake Mountain fault source has two alternative approaches to assessing slip rate. The portion of the logic tree for the Rattlesnake Mountain fault that differs from the other fault sources is shown in Figure 6.

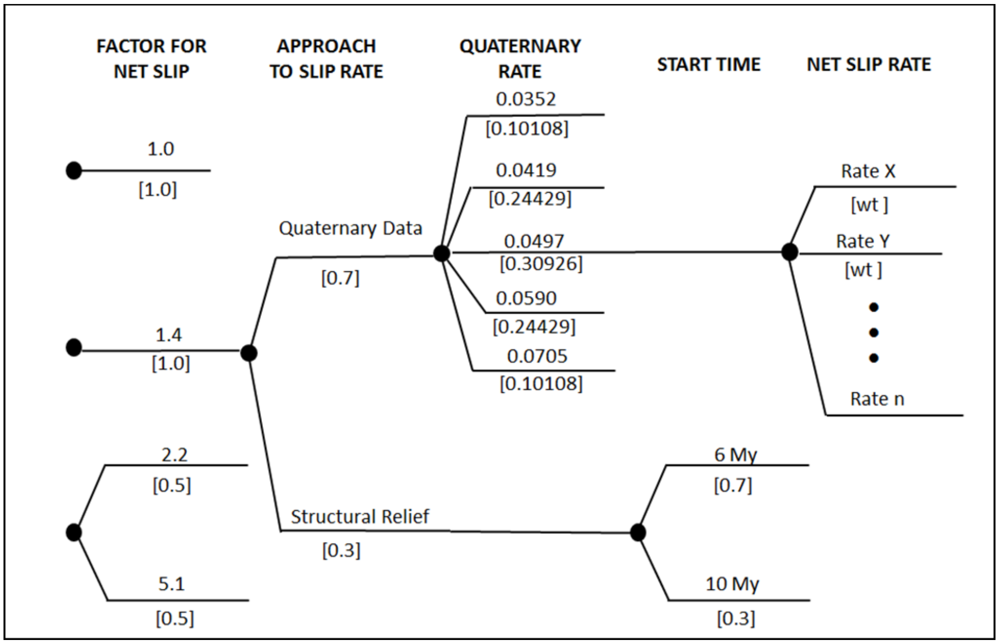

Figure 6. Logic Tree for the Rattlesnake Mountain Fault Source

After the node of the fault logic tree for the factor for net slip (see Figure 5), the next node of the Rattlesnake Mountain logic tree is the approach to assessing slip rate. The alternative branches and their weights are as follows:

Use of Quaternary Data [0.7]
Use of Structural Relief [0.3].

Given the Quaternary data approach, five branches provide the average Quaternary rates of vertical separation are assessed in the next node of the logic tree:

Weight	Slip Rate (mm/yr)
[0.10108]	0.0352
[0.24429]	0.0419
[0.30926]	0.0497
[0.24429]	0.0590
[0.10108]	0.0705.

Given the structural relief approach, alternative start times and their weights are given in the next node of the logic tree for the Rattlesnake Mountain fault source.

The *Fault Segments* tab of the file *HID_alltables_20140317.xlsx* includes the dip slip, net slip, and net slip rate, for each structural relief, seismogenic thickness, topographic polygon width, fault dips, sense of slip, and start time for each fault segment. For Rattlesnake Mountain, the calculated values using the structural relief approach are given for the source titled “Rattlesnake Mountain.” The calculated values of net slip rate using the Quaternary data approach are given for the source titled “Rattlesnake Mountain Quaternary Rate.”

The slip rates for the Arlington, Laurel, Luna Butte, and Maupin faults are directly assessed, rather than based on structural relief. The net slip rates for each of these fault sources are given by the following distribution:

0.1 mm/yr	[0.1]
0.05 mm/yr	[0.5]
0.01 mm/yr	[0.4].

The net slip rate values for all of the fault segments serve as inputs to the subsequent assessment of recurrence using slip rate, as discussed below in "Earthquake Recurrence for Fault Segments."

Net slip rate cumulative distribution functions for all fault sources are given in the file *Slip Rate cdfPlots.xlsx.*

Characteristic Magnitudes, Mchar, for Fault Sources

The logic tree for assessing the Mchar for the fault sources is shown in Figure 7. This assessment is for the entire fault. Accordingly, the characteristic rupture and the associated magnitudes are associated with any part of the fault along its length in the hazard analysis.

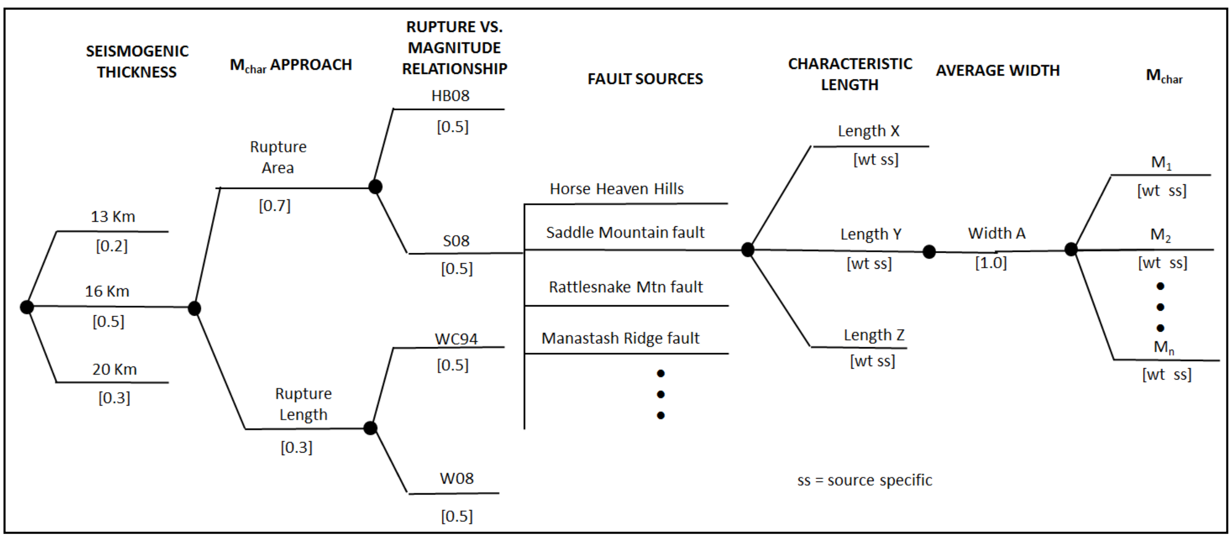

Figure 7. Logic Tree for Characteristic Magnitudes of Fault Sources

The assessment of seismogenic thickness is common to all fault sources that lie within the YFTB source zone, as discussed previously:

13 km [0.2]
16 km [0.5]
20 km [0.3].

The next node of the logic tree is the approach that is used to calculate the characteristic magnitude. The two alternative approaches are the use of rupture area and the use of rupture length. The weights associated with the alternative approaches are as follows:

Rupture area vs. magnitude [0.7]
Rupture length vs. magnitude [0.3].

The alternative rupture area relationships and their relative weights are as follows:

Hanks and Bakun (2008): HB08 [0.5]

$\mathbf{M}$ = log A + 3:98 for A≤ 537 km^2; and
$\mathbf{M}$ = 1.33 log A + 3:07 for A>537 $km^{2.}$

Stirling et al. (2008): S08 [0.5]

$\mathbf{M}$ = 4.18 + 2/3 log W + 4/3 log L (where L is rupture length, and W is width).

The alternative rupture length relationships and their relative weights are the following:

Wells and Coppersmith (1994): WC94 [0.5]
$\mathbf{M}$ = 4.49 + 1.49 log L

Wesnousky (2008): W08 [0.5]
$\mathbf{M}$ = 4.11 + 1.88 log L.

The remaining assessments are fault-specific, as indicated by the vertical bar in the logic tree.

The next node of the logic tree is the assessment of the length of rupture associated with the characteristic earthquake for each fault source. The assessments of rupture lengths for each fault are given in Table 6.

Table 6. Characteristic Rupture Lengths for Fault Sources

	Characteristic Rupture Length	
Fault Source	Length (km)	Weight
Ahtanum Ridge-Rattlesnake Hills	45	0.5
	60	0.5
Arlington	35	0.5
	50	0.5
Cleman Mountain	23	1.0
Columbia Hills	20	0.3
	35	0.5
	50	0.2
Frenchman Hills	27	0.4
	37	0.4
	45	0.2
Horn Rapids Fault	24	1.0
Horse Heaven Hills	35	0.3
	45	0.6
	50	0.1

Table 6. (contd)

Fault Source	Characteristic Rupture Length	
	Length (km)	Weight
Laurel	35	0.5
	50	0.5
Luna Butte	35	0.5
	50	0.5
Manastash Ridge	20	0.2
	35	0.5
	40	0.3
Maupin	35	0.5
	50	0.5
Rattlesnake Mountain	38	1.0
RAW	50	1.0
Saddle Mountain	45	0.5
	55	0.5
Selah Butte	22	1.0
Toppenish Ridge	30	0.4
	55	0.6
Umtanum-Gable	20	0.1
	30	0.5
	40	0.4
Wallula Fault	50	1.0
Yakima Ridge	20	0.1
	50	0.5
	70	0.4

Given these lengths, the area of rupture associated with the characteristic earthquake is calculated using the length-weighted average downdip width across all segments for each fault. The assessed rupture lengths and widths provide the rupture areas that are used to calculate the Mchar for each fault source, as shown in the logic tree.

The assessments of Mchar from rupture length and rupture area, as well as the weights associated with each approach, are combined to arrive at a distribution of Mchar for each fault source. The assessments of characteristic lengths and their associated weights are given in the *Entire Faults* tab of the file *HID_alltables_20140317.xlsx*. The Mchar distributions for the fault sources are given in the file *Mchar Mmax hisPlots.xlsx.*

Earthquake Recurrence for Fault Segments

The assessments for earthquake recurrence are related to the data and approaches that are used to assess earthquake recurrence for the fault segments, as given in the logic tree shown in Figure 8.

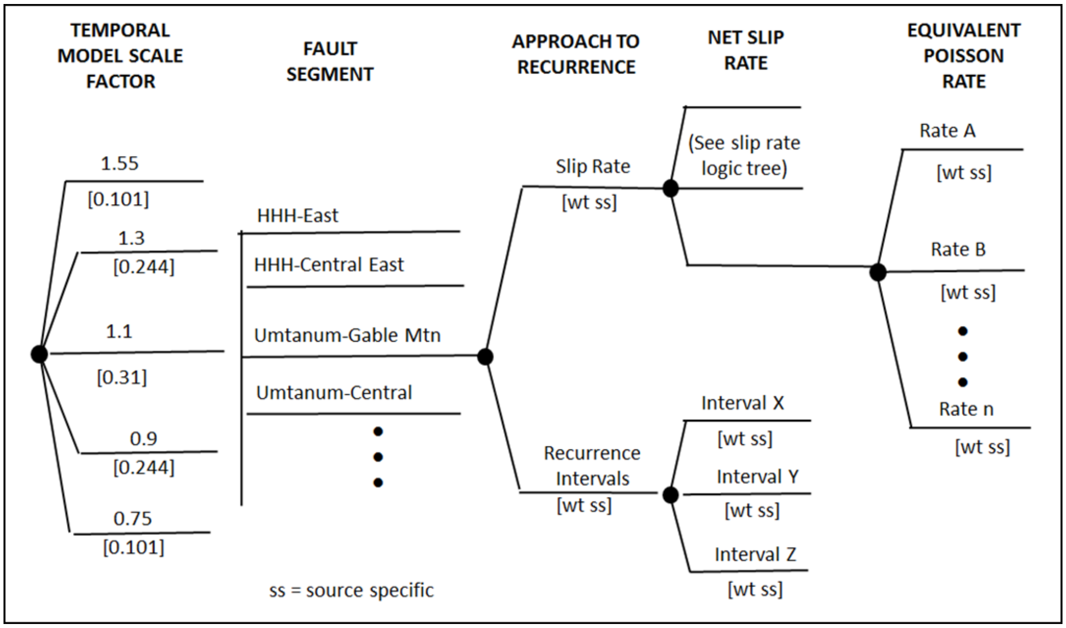

Figure 8. Logic Tree for the Recurrence Characteristics of Fault Segments

The first node of the logic tree is a "temporal model scale factor" that accounts for the physical process of strain accumulation and release (renewal model) to describe temporal model for each fault segment. The renewal process is assessed to apply to the characteristic part of the recurrence distribution and not to the exponential part, which expresses the recurrence of smaller magnitudes. This assessment is "global" and applies to all fault sources. The temporal model scale factors are multipliers on the mean Poisson rates to arrive at an equivalent Poisson rate that reflects the renewal process. The scale factors and their weights are as follows:

1.55	[0.101]
1.3	[0.244]
1.1	[0.31]
0.9	[0.244]
0.75	[0.101].

The remaining assessments are fault-segment-specific, as indicated by the vertical bar in the logic tree.

The next node of the tree is the identification of the approach that is used to estimate the recurrence of fault segments, which are the use of fault slip rates or paleoseismic recurrence intervals. The assessment of weights is fault-specific and, except for the Ahtanum Ridge-Rattlesnake Hills, Toppenish Ridge, and RAW fault sources, recurrence interval data are not available and that approach is therefore given zero weight.

The weights associated with the two recurrence approaches for the Ahtanum Ridge-Rattlesnake Hills and the Toppenish Ridge fault sources are as follows:

Slip rate approach	[0.7]
Recurrence intervals approach	[0.3].

For the RAW fault source, the weights for the alternative approaches are as follows:

Slip rate approach [0.95]
Recurrence intervals approach [0.05].

Given the recurrence intervals approach for RAW, the alternative assessments of the number of paleo-earthquakes and their weights are as follows:

3 earthquakes [0.2]
2 earthquakes [0.8].

For Ahtanum Ridge-Rattlesnake Hills and Toppenish Ridge, all segments of the fault source are assessed to be characterized by the same recurrence intervals that are defined along a single segment. However, the recurrence rates are weighted by the applicable moment rate for each segment, which is a function of the segment length, downdip width, and net slip rate. The recurrence intervals given above apply to the entire RAW source.

Given the recurrence interval approach, the assessed recurrence rates for Ahtanum Ridge-Rattlesnake Hills, Toppenish Ridge, and RAW fault sources are given in Table 7 and in the file *HID_Recurrence_Interval_Rates.xlsx).*

Table 7. Recurrence Rates for AR-RH, TR, and RAW Fault Sources Based on Recurrence Interval Data

Weight	Poisson Rate	BPT Equivalent Poisson Rate for α:				
		0.6	0.7	0.8	1.0	1.35
Ahtanum Ridge Segment						
0.101	7.300E-06	7.762E-08	1.259E-07	1.660E-07	2.138E-07	2.512E-07
0.244	1.630E-05	1.820E-06	2.399E-06	2.818E-06	3.162E-06	3.162E-06
0.310	2.750E-05	1.023E-05	1.148E-05	1.202E-05	1.202E-05	1.096E-05
0.244	4.320E-05	3.162E-05	3.020E-05	2.884E-05	2.570E-05	2.138E-05
0.101	7.010E-05	6.918E-05	6.026E-05	5.495E-05	4.677E-05	3.890E-05
Toppenish Ridge – East Segment						
0.101	4.300E-06	1.000E-20	1.000E-20	1.000E-20	9.333E-17	4.677E-15
0.244	9.700E-06	1.000E-20	3.311E-16	2.692E-14	3.715E-12	1.202E-10
0.310	1.650E-05	4.786E-15	9.333E-13	2.884E-11	1.549E-09	3.090E-08
0.244	2.580E-05	1.514E-11	5.754E-10	6.457E-09	1.202E-07	1.230E-06
0.101	4.190E-05	2.512E-08	2.291E-07	9.120E-07	4.571E-06	1.862E-05

Table 7. (contd)

Weight	Poisson Rate	BPT Equivalent Poisson Rate for α:				
		0.6	0.7	0.8	1.0	1.35
			RAW – Finley Quarry			
0.101	7.300E-06	7.762E-08	1.259E-07	1.660E-07	2.138E-07	2.512E-07
0.244	1.630E-05	1.820E-06	2.399E-06	2.818E-06	3.162E-06	3.162E-06
0.310	2.750E-05	1.023E-05	1.148E-05	1.202E-05	1.202E-05	1.096E-05
0.244	4.320E-05	3.162E-05	3.020E-05	2.884E-05	2.570E-05	2.138E-05
0.101	7.010E-05	6.918E-05	6.026E-05	5.495E-05	4.677E-05	3.890E-05

The next node of the tree is the slip rate, which is the net slip rate that has been derived for each fault segment, as discussed previously. The distribution of net slip rates and fault segment areas, which are needed to implement the slip rate approach, are provided in the *Fault Segments* tab of the file *HID_alltables_20140317.xlsx*.

The characteristic model of Youngs and Coppersmith (1985) is used with the assessed fault-specific slip rates and characteristic magnitudes Mchar. The characteristic model is implemented with the default parameters; i.e., the probability density function (pdf) includes a 0.5 magnitude-wide boxcar centered on the characteristic magnitude Mchar and an exponential portion defined such that the value of the rate for Mchar – 1.25 matches the characteristic rate. The characteristic earthquake model should be implemented by using the source-specific slip rates and recurrence intervals for Mchar if that information is available. The exponential part of the characteristic earthquake model uses the b-value for the YFTB seismic source zone.

The recurrence rates based on slip rate for each of the fault sources across all elements of the fault source logic trees are given in the file *FAULTS_yc85.xlsx*.

CASCADIA SOURCES

Cascadia Intraslab Source

The Cascadia intraslab source (C-slab) is shown in Figure 10 and the coordinates are given in the file *Slab Source Coords* tab in the file *HID_alltables_20140317.xlsx*. The basic model for the intraslab source is the same as that given in the BC Hydro PSHA (BC Hydro 2012). The differences from the BC Hydro model are identified here.

The easternmost extent of the intraslab source is defined by the depth contour that is associated with the interpreted downdip boundary of the source. The assessment of that depth contour is as follows:

80 km [0.2]
90 km [0.2]
100 km [0.6].

The recurrence for the intraslab source is calculated using the new intraslab earthquake catalog developed for the Hanford PSHA. The model for the spatial variation of recurrence parameters is based entirely on spatial smoothing of the observed seismicity (see file RECURRENCE_ZONES.*xlsx)*.

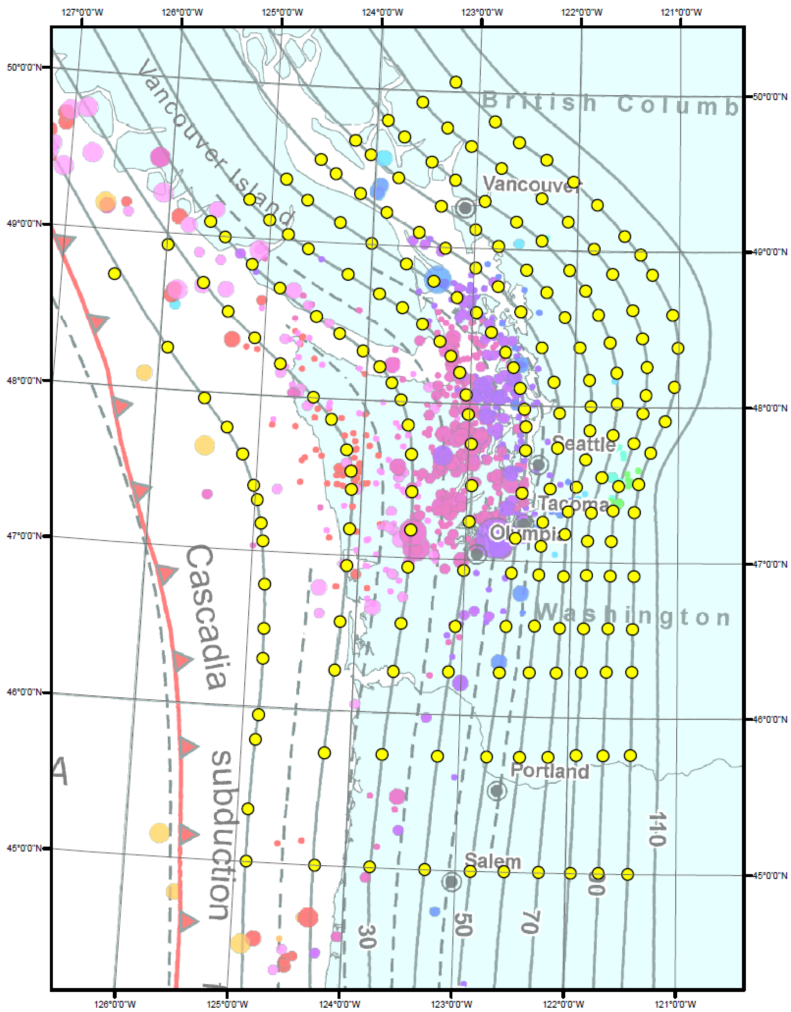

Figure 10. Map Showing the Cascadia Intraslab (C-slab) Source. The yellow dots define the surface of the slab in three-dimensions.

Cascadia Plate Interface Source

The Cascadia plate interface source (C-interface) is defined according to the geometry that is given in the BC Hydro (2012) characterization, as shown in Figure 11.

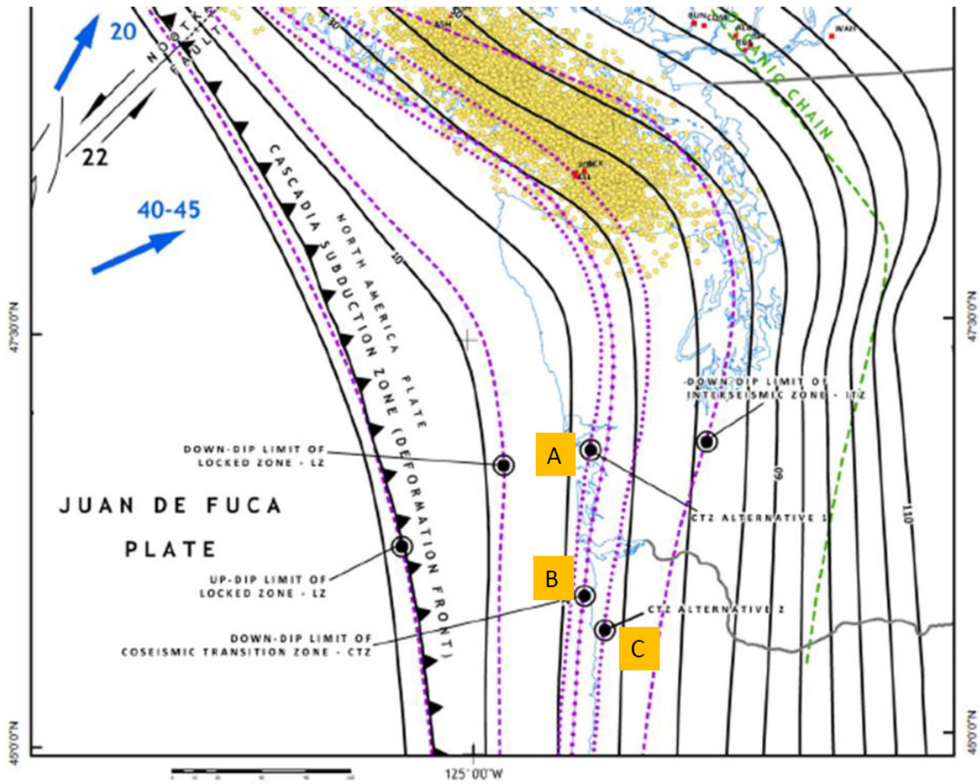

Figure 11. Plate Interface Source Geometry as Given in the BC Hydro (2012) Model. Alternative locations of the easternmost extent of the plate interface, drawn on the top of the slab, are shown by the contours A, B, and C.

The basic model for the plate interface source is the same as that given in the JBA et al. (2012), which slightly simplifies the model given in the BC Hydro PSHA (2012). The differences from the Mid-Columbia model are identified here.

The three alternative locations for the easternmost extent of the coseismic transition zone (CTZ) (shown in Figure 11) are assigned the following weights:

Base of CTZ (B)	[0.2]
10 km updip of base of CTZ (A)	[0.1]
30 km downdip of base of CTZ (C)	[0.7].

References

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Hanks TC and WH Bakun. 2008. **M** − log A observations of recent large earthquakes. *Bulletin of the Seismological Society of America* 98(1):490–494.

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NRC (U.S. Nuclear Regulatory Commission). 2012. *Central and Eastern United States Seismic Source Characterization for Nuclear Facilities Project*. NUREG-2115, Washington, D.C.

Youngs RR and KJ Coppersmith. 1985. Implications of fault slip rates and earthquake recurrence models to probabilistic hazard estimates. *Bulletin of the Seismological Society of America* 75: 939−964.

Attachments

Excel files:

FocalDepth_Dist.xlsx
DepthAnalysis_EM185.xlsx
Ztor_dist.xlsx
HID_alltables_20140317.xlsx
FAULTS_exp_20131114.xlsx
Capture_area-coordinates_20131018.xlsx
RECURRENCE_ZONES.*xlsx*
Slip Rate cdfPlots.xlsx
Mchar Mmax hisPlots.xlsx
HID_Recurrence_Interval_Rates.xlsx
FAULTS_yc85.xlsx